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EFFECTIVENESS OF MOTOR IMAGERY TRAINING ON IMPROVING UPPER EXTREMITY FUNCTIONAL ABILITY POST STROKE: A SYSTEMATIC REVIEW

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ABSTRACT

Increasingly acknowledged for its ability to improve motor function and neuroplasticity in stroke therapy is motor imagery (MI) training. Variability in techniques and results, however, calls for a methodical assessment to combine the data. Objective: The goal of this study was to assess whether MI training will help stroke patients achieve better motor performance and other rehabilitation results. Method: After a thorough search across five databases using PubMed, Scopus, Google Scholar, Web of Science, and Cochrane Library in line with PRISMA criteria, we took ten works published between 2023 and 2025 under consideration. Resulting in 578 entries and Ultimately 10 studies were included in the review. methodological quality was assessed using JBI critical assessment techniques. Result:Ten research were examined and MI-based therapies clearly improved upper limb function, neuroplasticity, and attentional control. MI with BCI showed improved cortical activation, brain connection, and muscular strength. In severe cases especially, MI combined with TMS enhanced motor recovery. Furthermore, MI training enhanced with virtual reality or voice direction improved psychological well-being and daily life activities. Conclusion: MI-based treatments—especially in conjunction with cutting-edge technologies—effectively enhance motor and cognitive performance in stroke victims. To maximise clinical use, future studies should standardise procedures, investigate reasonably priced delivery strategies, and evaluate long-term advantages.

Keywords: motor imagery; stroke rehabilitation; upper extremity function

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INTRODUCTION

Because of its significant effect on motor ability and quality of life, stroke remains a worldwide health issue ranking as a key cause of disability. Among stroke survivors, upper limb dysfunction is especially common; long-term disabilities sometimes limit everyday tasks and independence. Recent developments in neurorehabilitation have highlighted the possibility of motor image (MI) training—a cognitive strategy including the mental modelling of movement—to help motor recovery. MI training engages motor-related neural circuits similar to those triggered during real physical motions, so leveraging the neuroplasticity of the brain. Modern therapies increasingly combine MI with cutting-edge modalities including brain-computer interface (BCI) systems and neuromodulation techniques like transcranial magnetic stimulation (TMS). In stroke rehabilitation, these techniques have shown encouraging results including better motor strength, cortical reorganisation, and attentional skills. While developing technologies are transforming MI applications, considerable variation in intervention methods, delivery environments, and measurable outcomes creates difficulties for general acceptance and standardising.

Notwithstanding these developments, important knowledge about the long-term effectiveness and best integration of MI with complementary treatments are lacking. Studies already in publication have mostly concentrated on short-term gains, sometimes ignoring long-term psychological effects and consistent functional recovery. Furthermore complicating the generalisation of results are differences in patient response to MI driven by variables such stroke degree, lesion site, and cognitive capacity. In healthcare environments, standardised protocols and affordable delivery systems currently lacking limits access and scalability. Unlocking the full therapeutic potential of MI-based techniques and guaranteeing fair benefits across various patient populations depend on closing these gaps by thorough research and customised treatments to assess whether MI training will help stroke patients achieve better motor performance and other rehabilitation results.

METHOD

Developed utilising the Joanna Briggs Institute (JBI) approach for systematic reviews, this systematic literature review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. Using data from several research, the review sought to evaluate MIT's upper extremity motor performance in helping stroke victims. Methodically we examined five electronic databases: Pubmed, Scopus, Google Scholar, Web of Science, and Cochrane Library. The search plan identified pertinent research on motor imaging and stroke therapy using a Boolean technique. Careful mixing of the keywords guarantees thorough covering of the issue. The search turned for terms related to motor imagery concepts like "motor imagery," "mental practice," "mental rehearsal," "action observation," and "mental simulation." These were matched with phrases characterising stroke conditions: "stroke," "cerebrovascular accident," "cerebral ischaemia," and "brain infarction." The search included words like "upper extremity," "upper limb," "arm," "hand," "wrist," and "finger," therefore narrowing the emphasis on the afflicted bodily parts. At last, words stressing rehabilitation goals and outcomes were included: "rehabilitation," "recovery," "function," "movement," "motor control." This all-encompassing approach helped to identify a great range of studies pertinent to the junction of motor imagery and stroke recovery.

Inclusion And Exclusion Criteria

Regardless of stroke type—acute, subacute, or chronic—the review included research on adult stroke patients (≥18 years), who suffered with upper extremity motor deficits. Along with action observation therapy, eligible methods included motor imagery training—either as a stand-alone therapy or in conjunction with traditional techniques. Comparators consisted in any suitable comparative design or control group. While secondary effects looked at neurophysiological processes like fMRI or TMS-evoked potentials, primary outcomes concentrated on motor function tests. Study plans approved ranged from cohort and case series with at least three individuals to randomised and non-randomized studies. Included were only peer-reviewed English-language publications released between January 2023 and March 2025. Exclusion criteria excluded research including non-stroke illnesses, paediatric populations, or animals. Interventions lacking unambiguous definitions or isolatable effects of motor imagery were not included. Likewise not taken into account were case studies with less than three participants, qualitative research devoid of quantitative data, and articles devoid of results. omitted were outcomes unrelated to upper extremity function or without standardised measures; also omitted were non-English publications without translations or unpublished data lacking adequate depth.

Data Extraction

Data extraction used a consistent structure consistent with JBI recommendations. Important information acquired included research characteristics (authors, publication year, and design), specifications of the intervention (kind, procedure, duration, and setting), details of comparator groups, and outcome measurements including outcomes and assessment times. Using the JBI Critical Appraisal Checklist also allowed one to examine their own bias.

Review of Quality
Applied to their particular research designs, the JBI critical review approaches helped to evaluate the quality and bias risk of the included studies. The evaluated key factors reflected selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting), and additional possible biases. Although methodological limitations found during the assessment were considered in the synthesis and interpretation of the results, no studies were excluded just on the basis of quality.

Synthesised Data
Synthesis was done with an eye towards important facets of motor image (MI) training. The synthesis investigated the neurophysiological effects of MI, its clinical efficacy in enhancing upper extremity function, comparisons of different MI protocols, its applicability across several stroke phases, and its interaction with complementary rehabilitation techniques including brain-computer interfaces (BCI) and transcranial magnetic stimulation (TMS). Research quality, consistency, relevance, and effect sizes guided the evaluation of the results. Subgroup studies revealed variations in outcomes depending on stroke chronicity—acute, subacute, and chronic—and degree of early motor disability. This method gave a thorough knowledge of the several uses and results of MI treatments in stroke therapy.

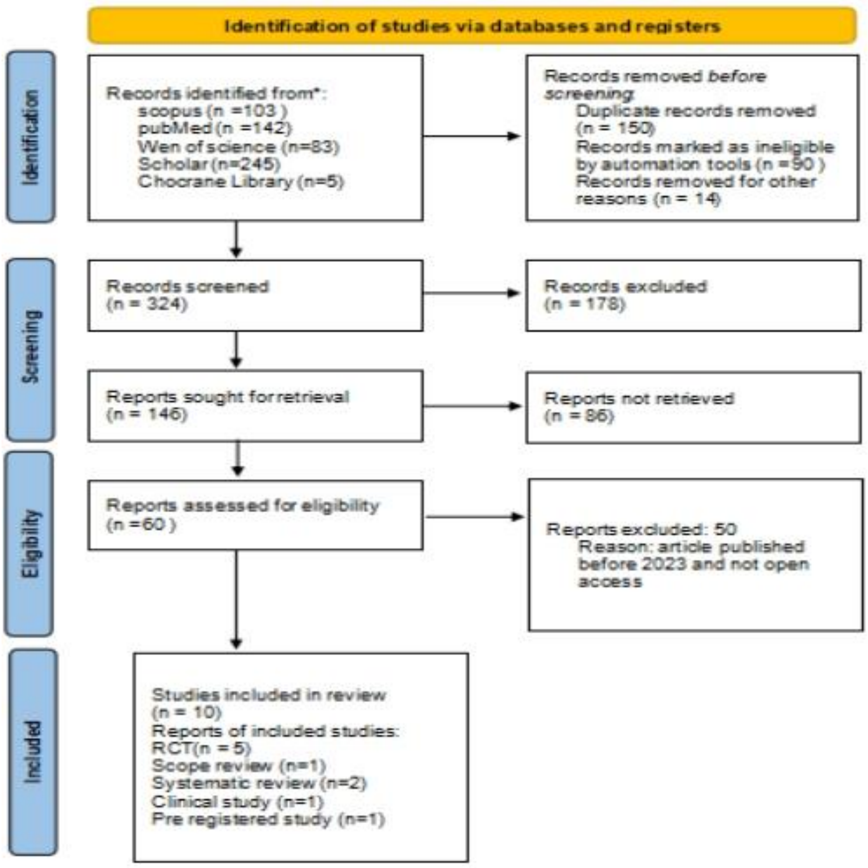

Figure 1. Prisma flow chart

The PRISMA flowchart outlines a systematic process for identifying, screening, and selecting studies for review. Initially, records were gathered from databases like Scopus, PubMed, Web of Science, Scholar, and the Cochrane Library, resulting in 578 entries. After removing duplicates (150 records) and excluding ineligible ones via automation or other criteria (104 records), 324 records remained for screening. During the screening phase, 178 records were excluded for not aligning with the study's objectives, leaving 146 reports for further evaluation. However, 86 reports could not be retrieved, often due to access issues. Of the remaining 60 reports, 50 were excluded, primarily for being outside the publication timeframe or inaccessible as open access. Ultimately, 10 studies were included in the review, comprising five randomized controlled trials, two systematic reviews, one scope review, one clinical study, and one pre-registered study. This systematic process ensures a transparent and rigorous selection of studies relevant to the research objectives.

Table 1
Characteristic Of The Study

No	Title, Authors, Year	Method (Study Design, Sample Size, Variables, Instruments, Statistical Analysis	Final Results
1	Efficacy of brain-computer interface training with motor imagery-contingent feedback in improving upper limb function and neuroplasticity among persons with chronic stroke: a double-blinded, parallel-group, randomized controlled trial (Kim et al., 2025)	Design: Double-blinded, parallel-group, randomized controlled trial conducted at a single rehabilitation hospital (August 2020 to December 2022). Sample: 27 people suffering with chronic stroke (25 finished the study: 13 in MI-independent feedback BCI group, 12 in MI-contingent feedback BCI group). Variables: dependent - upper limb function and brain plasticity; independent - BCI training with MI-contingent feedback vs. MI-independent feedback. Instrument : Active range of motion in wrist extension (AROM-WE), medical Research Council (MRC) scale for wrist extensor strength (MRC-WE), and resting-state electroencephalogram recordings for neural plasticity evaluation. Analysis: Comparison between groups with confidence interval reporting (mean difference = 0.52, 95% CI = 0.03–1.00, p = 0.036 for MRC-WE).	The findings validate the utilisation of MI-based BCI training as a potent complement to traditional rehabilitation methods for enhancing upper limb motor function and fostering brain plasticity in stroke survivors.
2	Effect of low-frequency repetitive transcranial magnetic stimulation combined with motor imagery training on upper limb motor recovery and primary motor cortex activation in stroke patients (Choi & Park, 2024)	Design: Two-group experimental control study Sample: 44 subacute stroke patients within 6 months of stroke onset (22 in experimental group: LF-rTMS + MIT; 22 in control group: LF-rTMS). Variables: - Independent: LF-rTMS combined with MIT vs. LF-rTMS alone. - Dependent: Upper limb motor recovery and primary motor cortex activation. Instruments: Fugl–Meyer Assessment for Upper Extremity (FMA-UE), Wolf Motor Function Test (WMFT), Action Research Arm Test (ARAT), motor-evoked potential (MEP) amplitude. Analysis: Paired t-test for pre- and post-intervention changes; independent samples t-test for group comparisons. Significance level set at $\alpha = 0.05$	This study demonstrated that motor imagery training magnetic induction therapy (MIT) in conjunction with low-frequency repeated transcranial magnetic stimulation (LF-rTMS) significantly improved upper limb motor function in stroke patients supporting its effectiveness in improving motor function and neurophysiological recovery.
3	Improved motor imagery skills after repetitive passive somatosensory stimulation: a parallel-group, pre-registered study (Kusano et al., 2024)	Design: Parallel-group, pre-registered study. Sample: 16 healthy participants randomly divided into an intervention group (with somatosensory stimulation) and a control group (rest only). Variables: - Independent: Somatosensory stimulation (St-NMES + passive movement stimulation) vs. rest. - Dependent: MI capability and cortical excitability. Instruments: Scalp EEG to measure event-related desynchronization (ERD) of the sensorimotor rhythm (SMR). Analysis: Pre-post comparisons and between-group analysis of ERD using statistical significance testing	This study demonstrated that the combination of neuromuscular electrical stimulation (St-NMES) and passive movement stimulation significantly improved motor imagery (MI) capabilities in healthy participants. These findings highlight the potential of somatosensory stimulation as an adjunct to motor imagery training, providing a promising approach to improving MI skills efficiently..
4	Motor imagery brain–	Design: Comparative clinical study.	The study demonstrated that MI-

No	Title, Authors, Year	Method (Study Design, Sample Size, Variables, Instruments, Statistical Analysis	Final Results
	computer interface rehabilitation system enhances upper limb performance and improves brain activity in stroke patients: A clinical study (Liao et al., 2023)	Sample: 40 hospitalized patients with ischemic stroke and motor deficits (20 in MI-BCI group; 20 in control group receiving physiotherapy alone). Variables: - Independent: MI-BCI combined with physiotherapy vs. physiotherapy alone. - Dependent: Upper limb motor performance, brain activity. Instruments: Fugl-Meyer Assessment (FMA) total score, FMA shoulder and elbow scores, FMA wrist scores, Motor Assessment Scale (MAS), non-contrast CT (NCCT), brain topographic maps. Analysis: Group comparisons pre- and post-intervention using descriptive and inferential statistics; reported mean differences with standard deviations	BCI combined with physiotherapy significantly outperformed physiotherapy alone in improving motor function of the upper limb and cerebral activity in stroke patients. The MI-BCI group demonstrated superior results. The findings confirm the feasibility of MI-BCI in actively inducing neural rehabilitation, with the severity of the patient's condition influencing the rehabilitation effect..
5	Effect of motor imagery-based brain-computer interface on upper limb function and attention in stroke patients with hemiplegia: a randomized controlled trial (Liu et al., 2023)	Design: Randomized controlled trial. Sample: 60 stroke patients with hemiplegia and impaired upper limb function. Patients were randomly assigned to the control group (CR group) or experimental group (BCI group) in a 1:1 ratio. Variables: - Independent: Motor imagery-based brain-computer interface (MI-BCI) training combined with conventional rehabilitation vs. conventional rehabilitation alone. - Dependent: Upper limb function (FMA-UE) and attention (ANT metrics). Instruments: Fugl-Meyer Motor Function Assessment of Upper Extremities (FMA-UE), Attention Network Test (ANT). Analysis: Statistical comparison of changes in outcome measures using confidence intervals and significance testing ($\alpha < 0.05$).	Motor imagery-based brain-computer interface (MI-BCI) training significantly improved upper limb function and attention in stroke patients compared to conventional rehabilitation alone. These findings suggest that MI-BCI combined with conventional rehabilitation is a feasible and effective approach to enhance motor and cognitive recovery in stroke patients.
6	Efficacy of Motor Imagery in the Rehabilitation of Stroke Patients: A Scope Review (Danilo et al., 2024)	Design: Systematic scope review Sample: Stroke patients with various severities and demographics from multiple studies. Variables: - Independent: MI interventions (standalone or combined with physical therapy). - Dependent: Motor recovery, balance, mobility, self-efficacy, neural plasticity. Instruments: Fugl-Meyer Assessment (FMA), Action Research Arm Test (ARAT), Timed Up and Go (TUG) test, Berg Balance Scale (BBS), Functional Independence Measure (FIM), General Self-Efficacy Scale (GSES), neuroimaging modalities. Analysis: Qualitative synthesis of RCT findings; focus on statistical significance and neurophysiological outcomes.	Motor imagery (MI) demonstrated significant efficacy as an adjunct to traditional rehabilitation. Across the studies reviewed, MI interventions resulted in substantial improvements in Upper Limb motor function (FMA, ARAT), mobility (TUG, BBS), and psychological well-being (FIM, GSES). Neuroimaging studies supported MI's role in activating cortical motor areas and promoting neural plasticity. Combining MI with physical therapy enhanced recovery outcomes.
7	Progress in the application of motor imagery training for full-cycle upper limb function rehabilitation of stroke patients (Xia et al., 2023)	Design: Narrative review of recent research on motor imagery training (MIT) for full-cycle upper limb rehabilitation in stroke patients, focusing on clinical and scientific research practices in China and abroad. Sample: Not applicable (review study). Variables: Examination of MIT's role across three stages: early stage (functional loss prevention), recovery stage (neural function remodeling), and later stage (improvement in daily function). Instruments: Literature analysis of studies on motor imagery training and its impact on sensorimotor network activation and upper limb rehabilitation outcomes.	Motor imagery training (MIT) plays a critical role in full-cycle upper limb rehabilitation for stroke patients. In the early stage of stroke, MIT helps prevent functional loss by activating the sensorimotor network. The findings underscore the importance of MIT as a central intervention in stroke rehabilitation, promoting functional protection and disability prevention throughout the

No	Title, Authors, Year	Method (Study Design, Sample Size, Variables, Instruments, Statistical Analysis	Final Results
		Analysis: Qualitative synthesis of existing research findings.	rehabilitation cycle
8	The Influence of Therapy Enriched with the Erigo®Pro Table and Motor Imagery on the Body Balance of Patients After Stroke—(Olczak et al., 2025)	Design: Randomised observational research. Sample :Sixty-six acute stroke patients (mean age 64.85 ± 18.62 years) were categorised into three groups, each comprising 22 participants: - Standard therapy - Standard therapy utilising Erigo®Pro - Standard therapy utilising Erigo®Pro supplemented with motor imagery. Variable: - Independent: A category of therapy. - Dependent: Enhancement of balance and muscle tension. Instruments: Trunk Control Test (TCT), Berg Balance Scale (BBS), Riablo™ device for static balance evaluation, tension assessment of transversus abdominis and multifidus muscles. Analysis : Statistical analyses involved paired comparisons with significant levels (TCT < 0.001, BBS < 0.001), and p-values were evaluated for frontal ($p = 0.023$) and sagittal ($p = 0.074$) balance. .	Motor imagery-enhanced therapy combined with the Erigo®Pro walking table showed the greatest improvements in trunk stability, balance. These findings suggest the importance of motor imagery as an adjunct to robotic-assisted rehabilitation for optimizing body balance and functional recovery in acute stroke patients.
9	Motor imagery as an intervention to improve activities of daily living post-stroke: A systematic review of randomized controlled trials (Lambert et al., 2023)	Design: Systematic review of randomized controlled trials (RCTs). Sample: Thirteen RCTs met inclusion criteria, with methodological quality ranging from poor to good (PEDro scores: 3–8). Variables: - Independent: Motor imagery (MI) training vs. conventional rehabilitation therapies. - Dependent: Activities of daily living (ADL) independence. Instruments: Physiotherapy Evidence Database (PEDro) scale for methodological quality assessment. Analysis: Qualitative synthesis of study results and evidence grading based on PEDro scores.	This systematic review found that motor imagery (MI) training is a low-risk and potentially effective tool for improving activities of daily living (ADL) independence in post-stroke patients. Audio-based MI training showed particular promise when integrated with other rehabilitation methods. However, the evidence quality was moderate to good, and results should be interpreted with caution due to variability in study methodologies. The review highlights the need for further research to establish evidence-based practice guidelines for MI training implementation post-stroke.
10	Motor imagery-based brain–computer interface rehabilitation programs enhance upper extremity performance and cortical activation in stroke patients (Z. Ma et al., 2024)	Design: CONSORT-compliant randomized controlled trial. Sample: 46 stroke patients with upper limb motor dysfunction (40 completed: 20 in BCI group, 20 in control group). Variables: - Independent: BCI therapy + conventional rehabilitation vs. conventional rehabilitation only. - Dependent: Upper extremity motor function, cortical activation. Instruments: Fugl–Meyer Assessment for Upper Extremity (FMA-UE), functional magnetic resonance imaging (fMRI) (task and resting states). Analysis: Correlation analysis of clinical assessments (FMA-UE) and functional measures (ALFF, ReHo, zALFF, zReHo).	BCI therapy, when integrated with traditional rehabilitation, markedly enhanced upper limb motor function in stroke patients. These findings support BCI therapy as an effective and prognostic tool for arm rehabilitation in poststroke hemiparesis, emphasizing the role of visual and spatial processing in motor recovery.

JBI Critical Appraisal :

Study	Random Sequence Generation (Selection Bias)	Allocation Concealment (Selection Bias)	Blinding of Participants and Personnel (Performance Bias)	Blinding of Outcome Assessment (Detection Bias)	Incomplete Outcome Data (Attrition Bias)	Selective Reporting (Reporting Bias)	Other Bias
Kim et al. (2025)	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Choi et al. (2024)	High risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Kusano et al. (2025)	High risk of bias	Some concerns	Some concerns	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Liao et al. (2024)	High risk of bias	Low risk of bias	Some concerns	Some concerns	Low risk of bias	Low risk of bias	Low risk of bias
Liu et al. (2023)	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Danilo et al. (2024)	High risk of bias	High risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
(Xia et al., 2023)	High risk of bias	Some concerns	Low risk of bias	Some concerns	Some concerns	Low risk of bias	Low risk of bias
(Olczak et al., 2025	Low risk of bias	Low risk of bias	Some concerns	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
(Lambert et al., 2023)	Low risk of bias	Some concerns	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
(Z.Ma et al., 2024)	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias

● (green) = Low risk of bias
● (yellow) = Some concerns
● (red) = High risk of bias

RESULT

Analysis of motor imagery therapies for upper limb rehabilitation in stroke patients produces the following primary conclusions from each of the ten research looking at this based on the study. Kim et al. (2025) found, in comparison to non-contingent feedback, brain-computer interface training with motor imagery-contingent feedback significantly improved upper limb function in chronic stroke sufferers. Their randomised controlled experiment showed notable increases in wrist extensor strength (mean difference = 0.52, 95% CI = 0.03-1.00, p = 0.036), therefore validating MI-BCI as a beneficial adjunct to usual treatment for enhancing motor recovery and brain plasticity. Choi and Park (2024) found in patients with subacute strokes that combining low-frequency repetitive transcranial magnetic stimulation (LF-rTMS) with motor imagery training provided better upper limb motor recovery results than LF-rTMS alone. Their experimental study revealed appreciable gains in numerous assessment measures, including the Fugl-Meyer Assessment, Wolf Motor Function Test, and Action Research Arm Test, so underlining the synergistic effect of these combination treatments on motor function and neurophysiological recovery.

In healthy subjects, somatosensory stimulation combining neuromuscular electrical stimulation with passive movement greatly improved motor imagery capacities according to Kusano et al. (2024). Their pre-registered study indicated significant increases in motor imagery skills measured by event-related desynchronisation of sensorimotor rhythm using EEG, implying that this method may help to maximise motor imagery training strategies for use in rehabilitation. For stroke patients with upper limb difficulties, liao et al. (2023) found that motor imagery brain-computer interface rehabilitation mixed with traditional physiotherapy provided noticeably better outcomes than physiotherapy alone. With findings modified by the degree of the patient's original condition, their clinical investigation showed notable increases in Fugl-Meyer Assessment scores and brain activity patterns, therefore validating MI-BCI's efficacy in enabling neural rehabilitation. Combining motor imagery-based brain-computer interface training with conventional therapy dramatically improved attention and upper limb function for Liu et al. (2023), who established for hemiplegic stroke patients. Their 60-person randomised controlled experiment revealed significant improvements in Fugl-Meyer Motor Function Assessment scores and Attention Network Test measurements, so confirming MI-BCI as a practical and successful strategy for fostering both motor and cognitive recovery following stroke.

According to a thorough scope review by Danilo et al. (2024), throughout several trials motor image therapies regularly showed significant increases in upper limb motor performance. With neuroimaging data supporting MI's function in activating cortical motor regions and promoting brain plasticity, their examination of several research results demonstrated notable increases in Fugl-Meyer Assessment scores, Action Research Arm Test performance, mobility, and psychological well-being. Xia et al. (2023) published data showing that for stroke patients with upper limb disability, motor imagery training is absolutely crucial throughout the complete rehabilitation cycle. Their narrative review underlined MI's relevance in the early stages for preventing functional loss by activating the sensorimotor network, during the recovery stage for encouraging neural remodelling, and in later stages for enhancing daily function, so establishing it as a basic intervention for comprehensive stroke rehabilitation. For acute stroke patients, conventional therapy augmented with both the Erigo®Pro walking table and motor imagery showed better trunk stability and balance than either conventional therapy alone or with just the Erigo®Pro, Olczak et al. (2025) found. With 66 subjects, their randomised observational study found notable increases in Trunk Control Test and Berg Balance Scale scores ($p < 0.001$), therefore highlighting the importance of motor imagery as a complement to robotic-assisted rehabilitation.

After methodically reviewing randomised controlled studies, Lambert et al. (2023) came to the low-risk, maybe successful conclusion that motor imagery training offers for post-stroke patients's activities of daily life independence. Though they observed diversity in methodological quality and urged more study to develop definite practice standards, their review of thirteen trials revealed very encouraging results for audio-based MI training when combined with other rehabilitation approaches. Programmes employing motor imagery-based brain-computer interfaces significantly raised cortical activation and upper extremity performance in stroke patients with upper limb disability, according Ma et al. (2024). Their Consort-compliant randomised controlled trial with forty participants confirmed increased Fugl-Meyer Assessment scores and functional magnetic resonance imaging characteristics in the BCI group, therefore supporting this technique as both a treatment and a prognosis tool for post-stroke arm rehabilitation

DISCUSSION

The Efficacy of Motor Imagery Training in Enhancing Motor Recovery

Motor imagery (MI) training has been extensively studied for its ability to enhance motor recovery in stroke patients. Its efficacy stems from the neuroplastic changes it induces within the sensorimotor cortex, promoting cortical reorganization and functional recovery. MI allows patients to mentally simulate movements without physical execution, effectively activating neural pathways critical for motor function. Studies consistently demonstrate that MI training improves motor performance, as measured by validated clinical tools like the Fugl-Meyer Assessment (FMA) and the Action Research Arm Test (ARAT). These findings align with the neurophysiological theories of cortical excitability, which postulate that mental simulation strengthens connectivity in motor networks (Choi & Park, 2024; Danilo et al., 2024).The integration of MI with rehabilitation technologies such as brain-computer interfaces (BCI) further amplifies its benefits. MI-BCI interventions enable real-time neurofeedback, allowing patients to actively modulate their neural activity, which strengthens motor-related pathways. Evidence from the reviewed studies highlights significant improvements in muscle strength, active range of motion, and functional connectivity with MI-BCI training. These improvements were particularly pronounced when MI was used as part of a structured rehabilitation protocol, emphasizing its utility as both a standalone and adjunctive therapy (Liu et al., 2023; Z. Z. Ma et al., 2024). Despite these benefits, the effectiveness of MI training varies across individuals, influenced by factors such as lesion location, cognitive abilities, and motor impairment severity. Patients with more severe impairments often show slower progress, underscoring the need for personalized protocols. Tailoring MI interventions to address individual variability can help optimize outcomes and ensure broader applicability in clinical practice.

Multimodal Approaches to Motor Imagery Training

Combining MI with other rehabilitation modalities has shown to enhance its efficacy. One notable approach involves integrating MI with functional electrical stimulation (FES). FES provides external stimuli to mimic voluntary muscle activation, complementing MI's focus on mental simulation. Studies indicate that this combination enhances neuroplastic changes and improves functional outcomes, particularly in patients with severe motor deficits. Such synergistic effects reinforce the potential of multimodal strategies in stroke rehabilitation (Angerhöfer et al., 2021; Vavoulis et al., 2023; Zhang et al., 2024). Similarly, the integration of transcranial magnetic stimulation (TMS) with MI has yielded promising results. TMS, especially in its low-frequency repetitive form (LF-rTMS), modulates cortical excitability, enhancing the brain's capacity to reorganize post-injury. When coupled with MI, TMS has been shown to significantly improve sensorimotor integration, leading to better voluntary movement control. These findings suggest that pairing neuromodulation techniques with MI can create an optimal environment for neural recovery (Choi & Park, 2024; Guo et al., 2021; Kang et al., 2021).The use of action observation (AO) in conjunction with MI offers another innovative approach. AO activates the mirror neuron system, facilitating motor learning through the observation of movements. Combining AO with MI has been shown to enhance corticospinal excitability and improve motor recovery. This dual approach creates a robust neural representation of movements, accelerating functional improvements in stroke patients (Almulla et al., 2022; Choi et al., 2022; Emerson et al., 2022; Temporiti et al., 2023).

Technological Integration in MI-Based Rehabilitation

The incorporation of advanced technologies such as virtual reality (VR) into MI training introduces a novel dimension to rehabilitation. VR creates immersive environments that mimic real-world motor tasks, enhancing patient engagement and adherence. Studies show that VR-assisted MI training provides real-time feedback, improving the precision of motor imagery and accelerating recovery. Patients undergoing VR-based MI interventions often report higher motivation levels and greater satisfaction, underscoring the psychological benefits of this approach (Ceradini et al., 2024; Kashif et al., 2022; Lakshminarayanan et al., 2023; Narayanan, 2022). BCI technology, when combined with MI, further strengthens its efficacy by enabling patients to monitor and control their neural activity. BCI-assisted MI training has demonstrated significant improvements in motor function and cortical activation. These findings highlight the potential of BCI as a tool for delivering personalized rehabilitation, allowing adjustments based on individual patient responses. However, the high costs and technical requirements of BCI systems remain barriers to widespread implementation (Feng et al., 2020; Hu et al., 2021; Liao et al., 2023; Sebastián-Romagosa et al., 2020; Wang et al., 2022).While technological integration enhances MI training, its success depends on balancing accessibility with innovation. Developing cost-effective and portable solutions is crucial for scaling these interventions. Additionally, integrating artificial intelligence into MI-based technologies could enable real-time adjustments and personalized therapy, ensuring that even resource-constrained settings can benefit from these advancements.

Cognitive and Psychological Benefits of MI Training

Beyond its motor benefits, MI training offers significant cognitive and psychological advantages for stroke patients. The structured mental exercises involved in MI activate attentional networks, promoting improvements in executive function and cognitive recovery. Stroke patients engaging in MI training often exhibit better focus and decision-making abilities, which complement their physical recovery. These cognitive gains are particularly beneficial for patients with coexisting cognitive impairments (Eaves et al., 2022). Psychologically, MI interventions have been linked to reduced anxiety and depression, common challenges faced by stroke survivors. The motivational aspects of MI, especially when combined with technologies like VR, help patients remain engaged and optimistic about their recovery journey. Studies emphasize the role of MI in fostering emotional resilience, which can significantly enhance adherence to rehabilitation programs (Bovonsunthonchai et al., 2020).

The dual impact of MI on physical and psychological health positions it as a holistic rehabilitation approach. By addressing both motor and emotional challenges, MI helps stroke survivors achieve comprehensive recovery, improving their quality of life and independence. However, integrating psychological assessments into MI protocols could further refine its application and ensure that emotional well-being is consistently addressed, (Agostini et al., 2021; Danilo et al., 2024; Wang et al., 2022).

Challenges and Future Directions

While MI training shows immense promise, several challenges must be addressed to optimize its clinical application. Variability in training protocols across studies complicates comparisons and generalizations. Establishing standardized guidelines for session duration, frequency, and outcome measures is essential for ensuring consistency and reliability in MI interventions. Accessibility remains a significant concern, particularly for advanced MI technologies like BCI and VR. High costs and the need for specialized equipment limit their adoption in routine clinical settings. Developing affordable and user-friendly systems will be key to expanding their reach. Incorporating home-based rehabilitation options can also enhance accessibility, allowing patients to continue therapy outside clinical environments.Future research should focus on long-term outcomes of MI training. While short-term benefits are well-documented, understanding the sustainability of these gains is crucial. Evaluating the effectiveness of booster sessions and maintenance strategies can help ensure that neuroplastic changes induced by MI are retained over time. Additionally, exploring the integration of MI with emerging technologies like artificial intelligence could open new avenues for personalized and adaptive rehabilitation.

CONCLUSION

In conclusion, the findings highlight the transformative potential of MI training in stroke rehabilitation. Its integration with advanced technologies and multimodal approaches enhances its efficacy, making it a cornerstone in modern neurorehabilitation practices. Addressing current challenges through innovation and standardization will unlock its full potential, paving the way for more inclusive and effective therapeutic strategies.The findings of this systematic review underscore the transformative potential of motor imagery (MI) training, especially when integrated with advanced technologies and multimodal rehabilitation approaches. For clinical practice, this highlights the need to incorporate MI as a core component of stroke rehabilitation programs. Its demonstrated efficacy in improving motor function, cognitive recovery, and psychological well-being suggests that it should be utilized not only in clinical settings but also adapted for home-based rehabilitation programs.

Implementing cost-effective tools such as VR or simplified BCI systems can make these interventions accessible to a wider patient population. Furthermore, standardizing MI protocols and training healthcare providers in its application can optimize outcomes and ensure consistent therapeutic delivery.In addition, rehabilitation centers should explore the integration of adjunctive techniques such as FES, TMS, and AO to maximize patient recovery. The dual impact of MI on physical and cognitive domains also suggests the importance of multidisciplinary collaboration, involving neurologists, psychologists, and physiotherapists, to create holistic care plans tailored to individual needs. Lastly, considering the motivational benefits of MI, practitioners should incorporate strategies that enhance patient engagement and adherence to rehabilitation regimens, ultimately improving long-term recovery outcomes.

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